

Dependence of satellite retrieved cloud optical depth and effective radius on Solar and Viewing Zenith Angles by comparing ARM ground-based retrievals

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University of Arizona (ARM results)**

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NASA Langley (CERES-MODIS)**

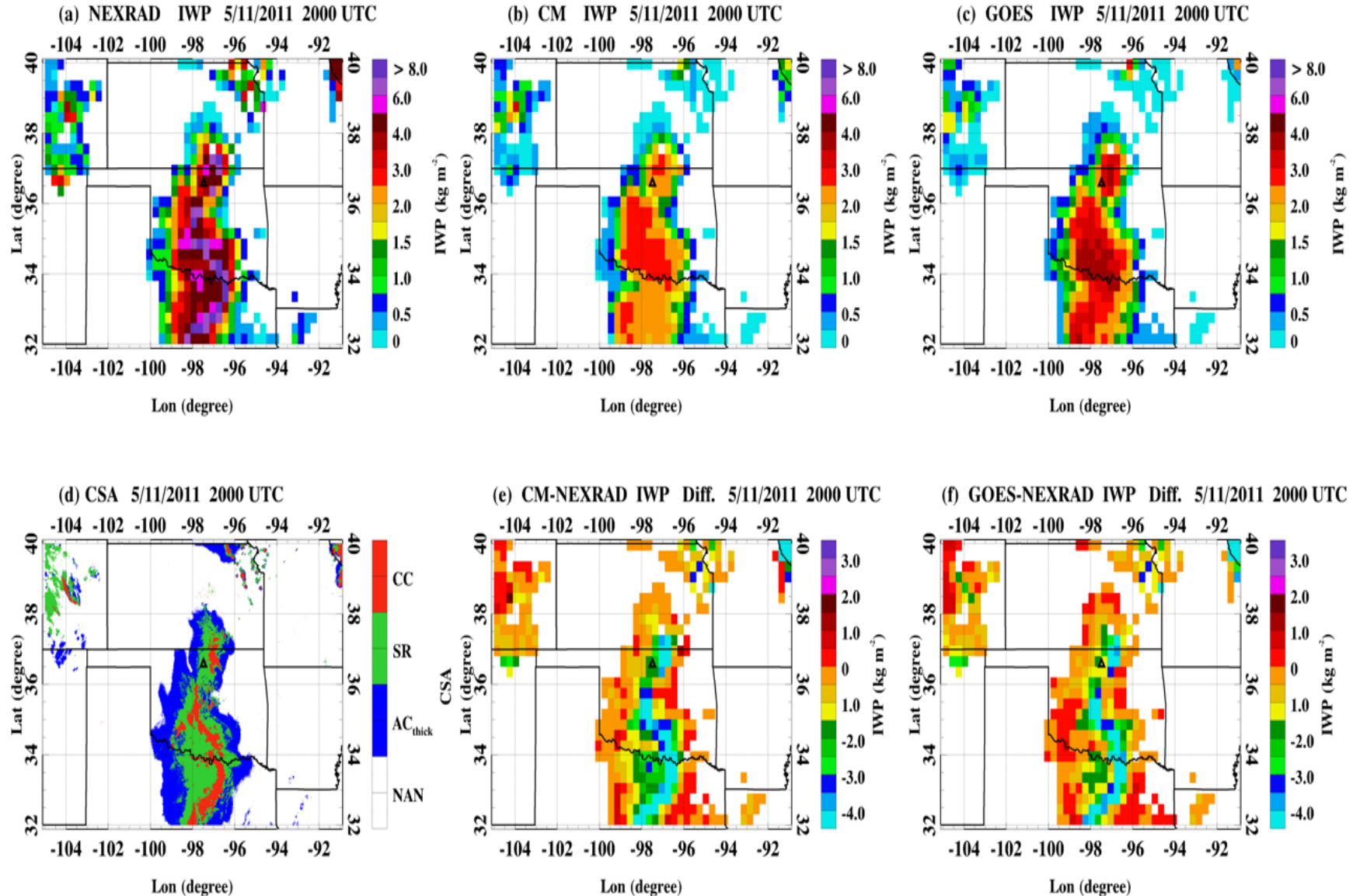
Zhibo Zhang and Frank Werner, UMBC (MODIS)

What my group can contribute to CERES Science Team?

Goal: To improve CERES STM cloud retrieval algorithms

Method: Using long-term ARM ground-based measurements and retrievals to validate NASA CERES Science Team retrieved different cloud properties over different climate regions.

What have been done since last CERES STM?



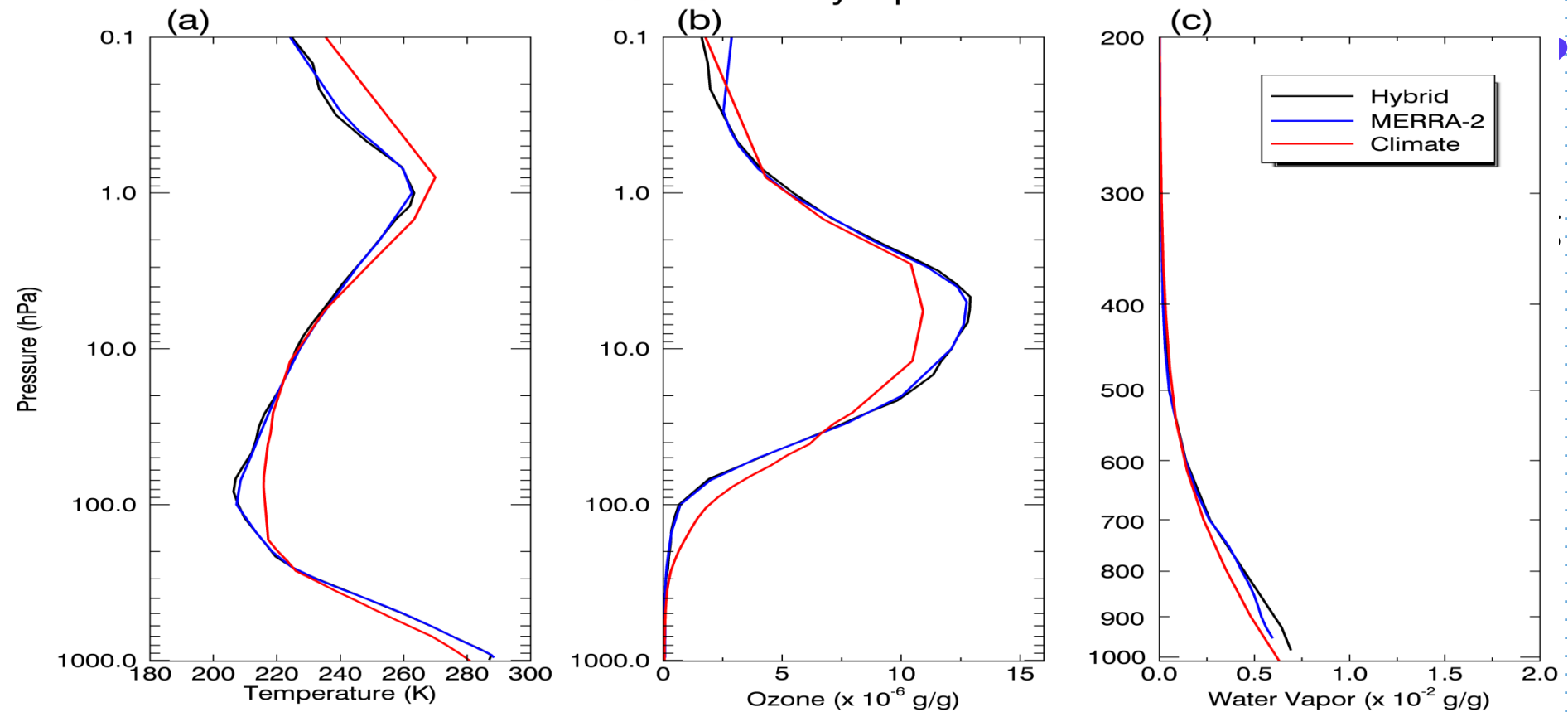
What have been done since last CERES STM?

- Tian, J., **X. Dong**, B. Xi, P. Minnis, S. Sun-Mack, and W.L. Smith Jr. 2016: Comparisons of water path in Deep Convective Systems among CERES-MODIS, GOES, and Radar Retrievals. In preparation for *JGR*.
- Zhang, Z., **X. Dong**, B. Xi, H. Song, P-L. Ma, S. Ghan, S. Platnick, and P. Minnis, 2016: Inter-comparisons of MBL cloud properties from two MODIS products, ground-based retrievals and a GCM over the ARM Azores site. Accepted by *JGR*.

→MODIS retrieved MBL tau and re agree well with CERES-MODIS results with $R=0.95$.

→However, both re are 1.5 um larger, tau are ~ 3 less than ARM retrievals at Azores

SGP Clear-sky Input Profiles

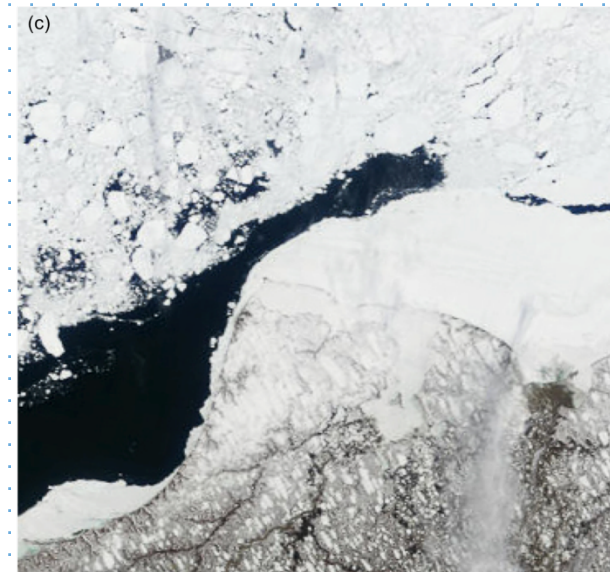
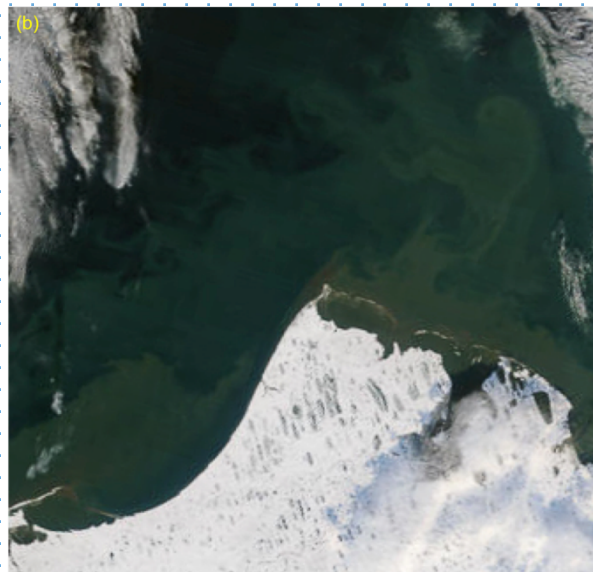


→ Comparing with soundings at three ARM sites, **MERRA-2** reanalyzed Temp, O₃, and water vapor agree very well except for drier below 700 mb.

→ Most of the RTM-calculated surface downward and TOA upward SW and LW fluxes agree within ~ 5 W/m² of the observations, which is within the uncertainties of the ARM and CERES measurements

What have been done since last CERES STM?

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- Zhang, Z., **X. Dong**, B. Xi, H. Song, P-L. Ma, S. Ghan, S. Platnick, and P. Minnis, 2016: Inter-comparisons of marine boundary layer cloud properties from two MODIS products and ground-based retrievals over the ARM Azores site. Submitted to *JGR*.
- Dolinar, E., **X. Dong**, B. Xi, J. Jiang, N.G. Loeb, 2016: A Clear-sky Radiation Closure Study Using a 1-D Radiative Transfer Model and Collocated Satellite-Surface-Reanalysis Data Sets. Accepted by *JGR*.
- **Dong, X., B. Xi, S. Qiu, P. Minnis, S. Sun-Mack, and F. Rose, 2016: A Radiation Closure Study of Arctic Cloud Microphysical Properties using the collocated satellite-surface data and Fu-Liou Radiative Transfer Model. *JGR*, 121, doi: 10.1002/2016JD025255.**



→The CERES-MODIS retrieved cloud microphysical properties agree well with ARM retrievals under both snow-free and snow conditions.

→A radiation closure has been reached at both surface and TOA for both snow-free and snow conditions.

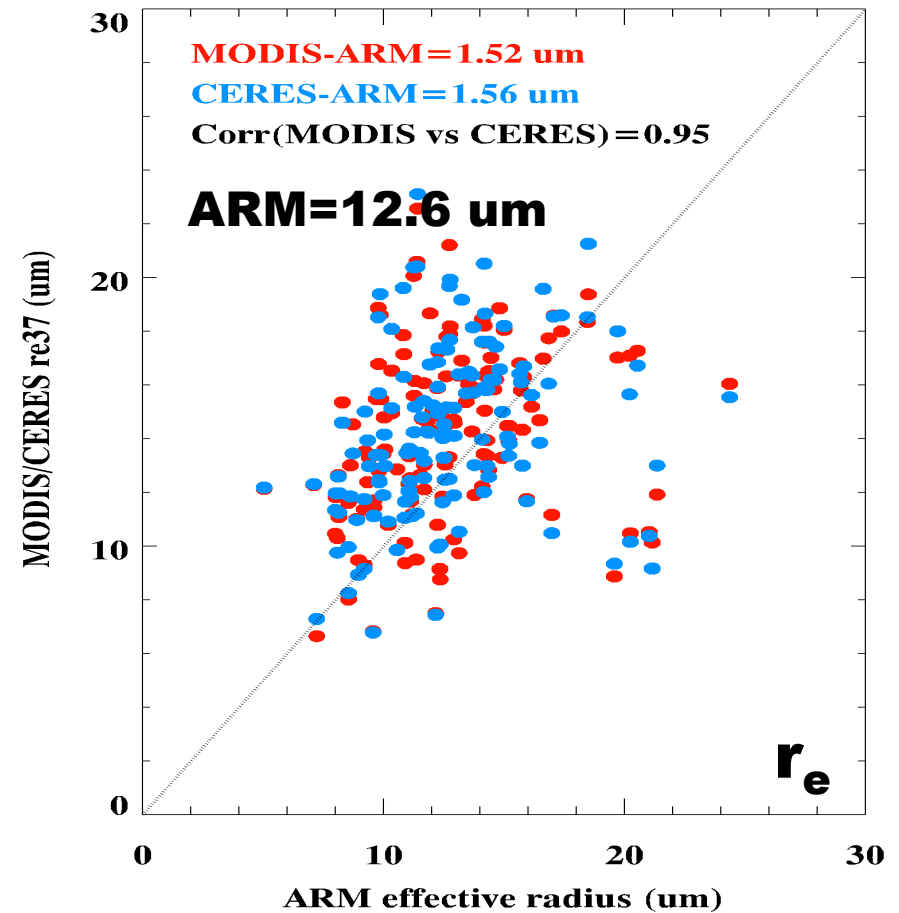
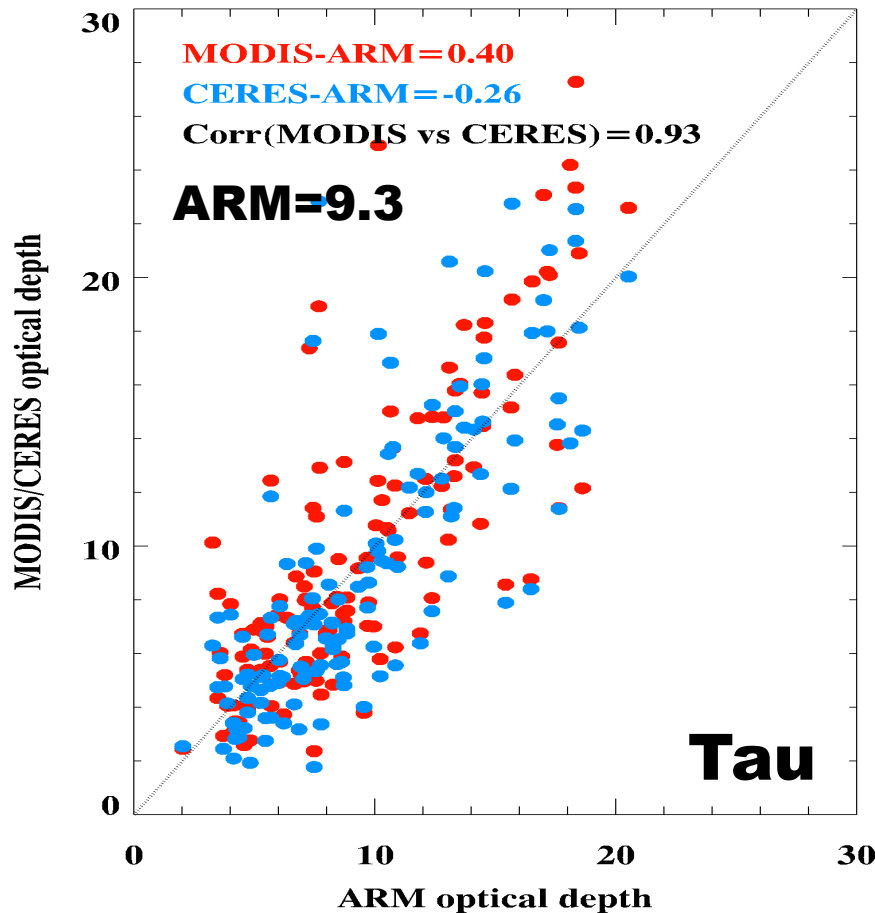
→A domain mean albedo is used to make apples-to-apples comparisons in cloud properties and to reach a radiation closure study.

Scientific questions for this study:

- **What are the similarities and differences between CERES-MODIS and MODIS teams retrieved cloud microphysical properties?**
- **Do satellite retrieved cloud properties depend on solar zenith angle (SZA) and viewing zenith angle (VZA)?**

Tau and r_e comparison between ARM and CERES/MODIS

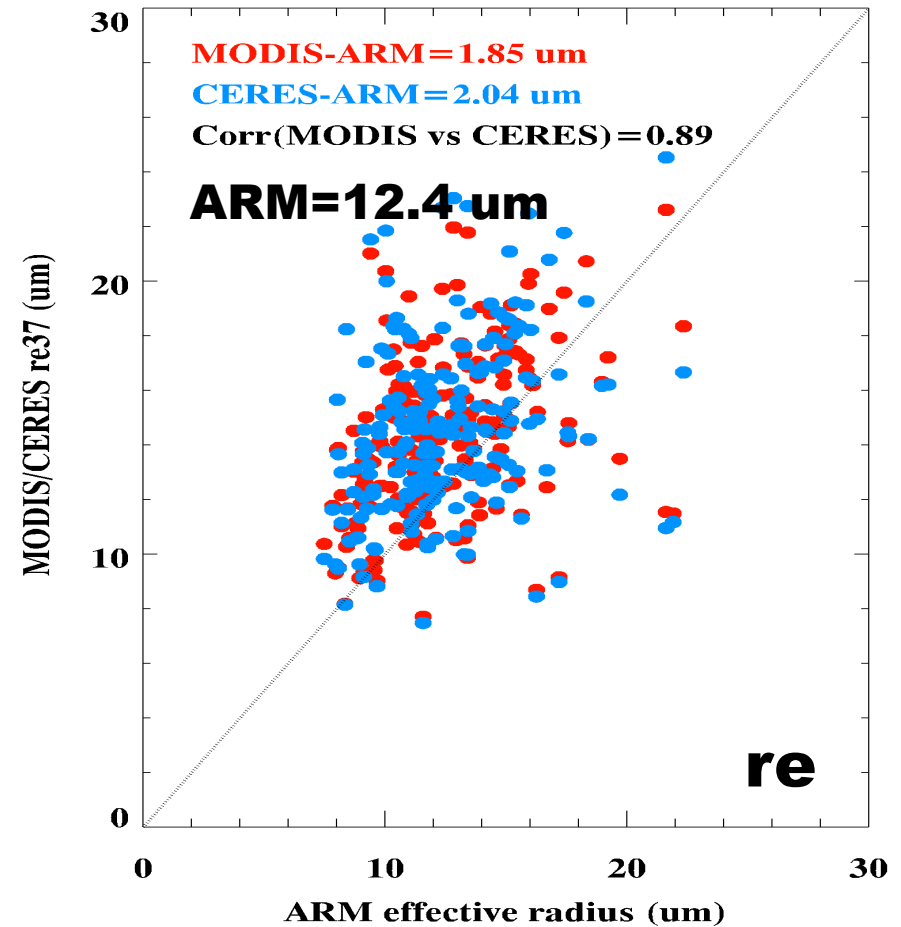
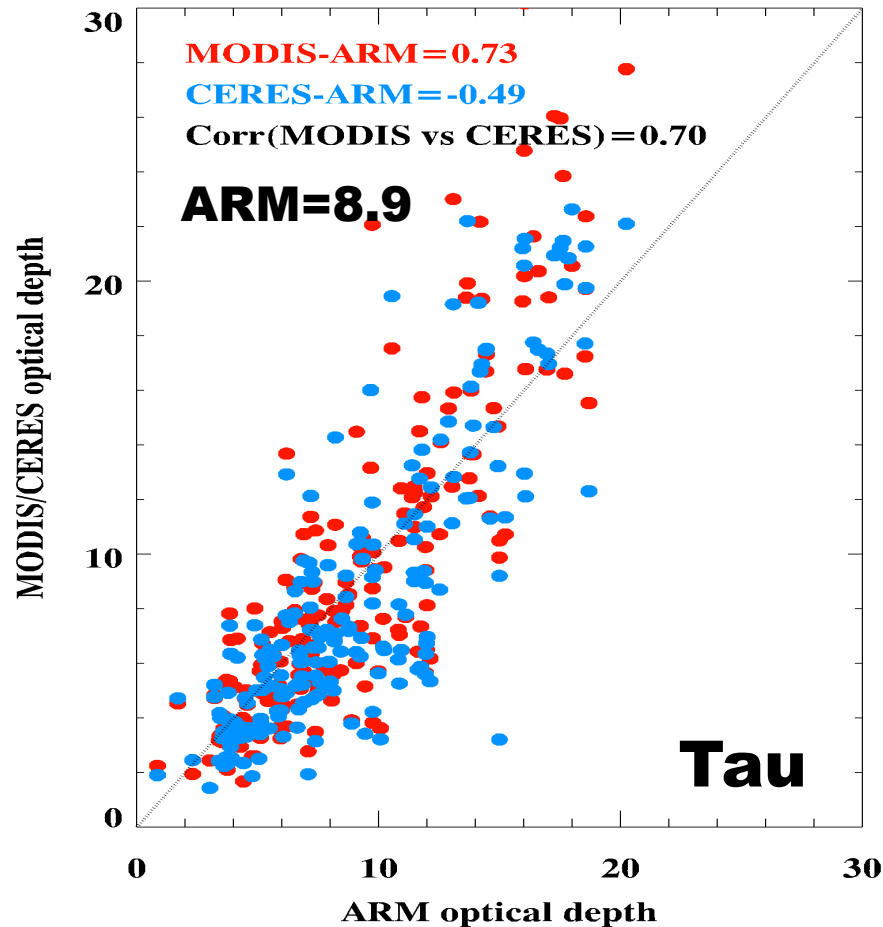
Aqua (snow-free)



- CERES and MODIS retrieved tau and r_e have very high correlations
- Both CERES and MODIS retrieved r_e are 1.5 um greater than ARM r_e . Same as their MBL cloud comparisons.
- MODIS tau is 0.4 higher, but CERES tau is 0.26 lower than ARM tau. Both Tau are closer to ARM retrievals than their MBL comparisons.

Tau and r_e comparison between ARM and CERES/MODIS

Terra (snow-free)

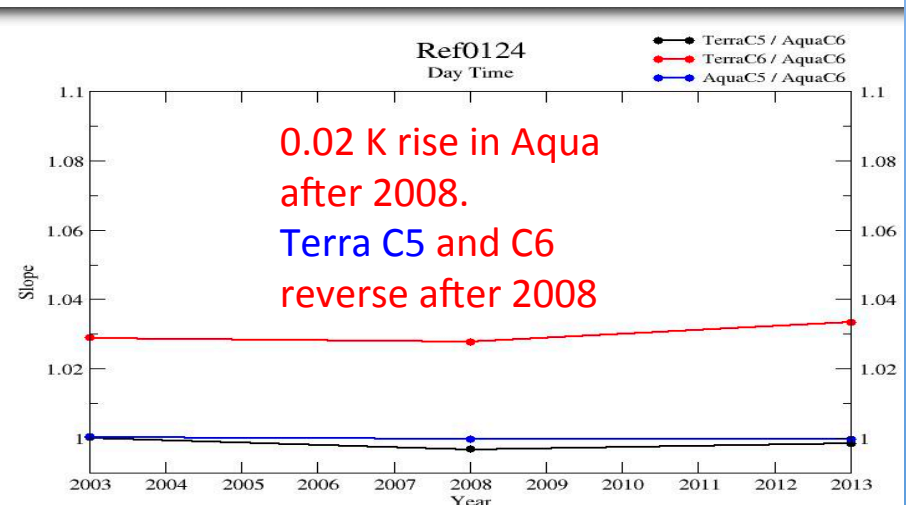
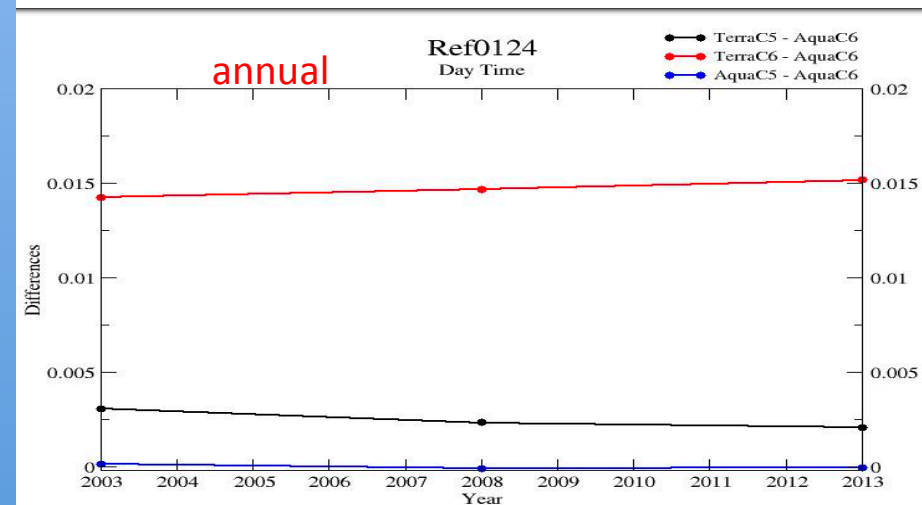
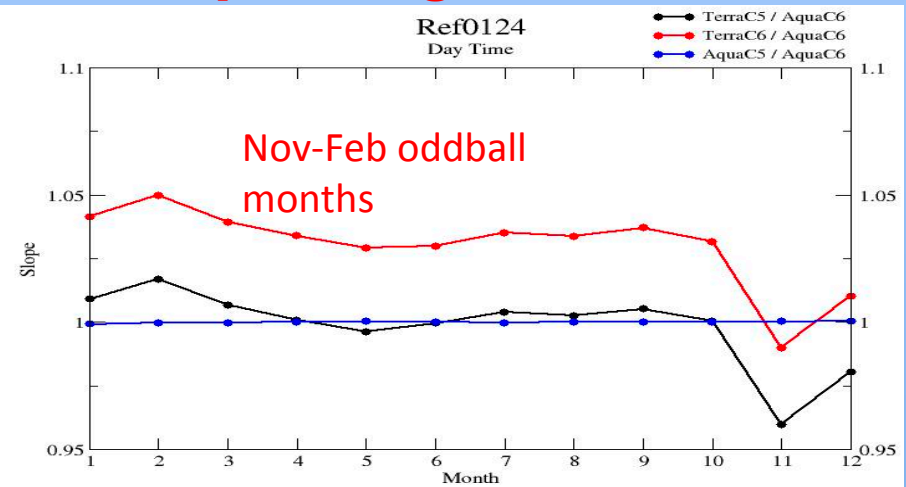
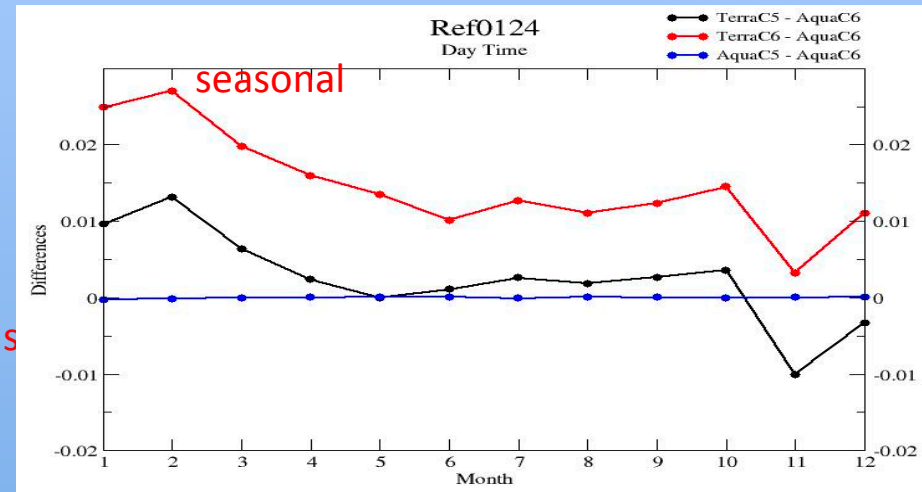


In general, the differences between ARM and CERES/MODIS for Terra are slightly larger, correlations are lower than their Aqua counterparts.

Snow: Near-IR channel (1.24 μm) C5-C6 changes

mean difference

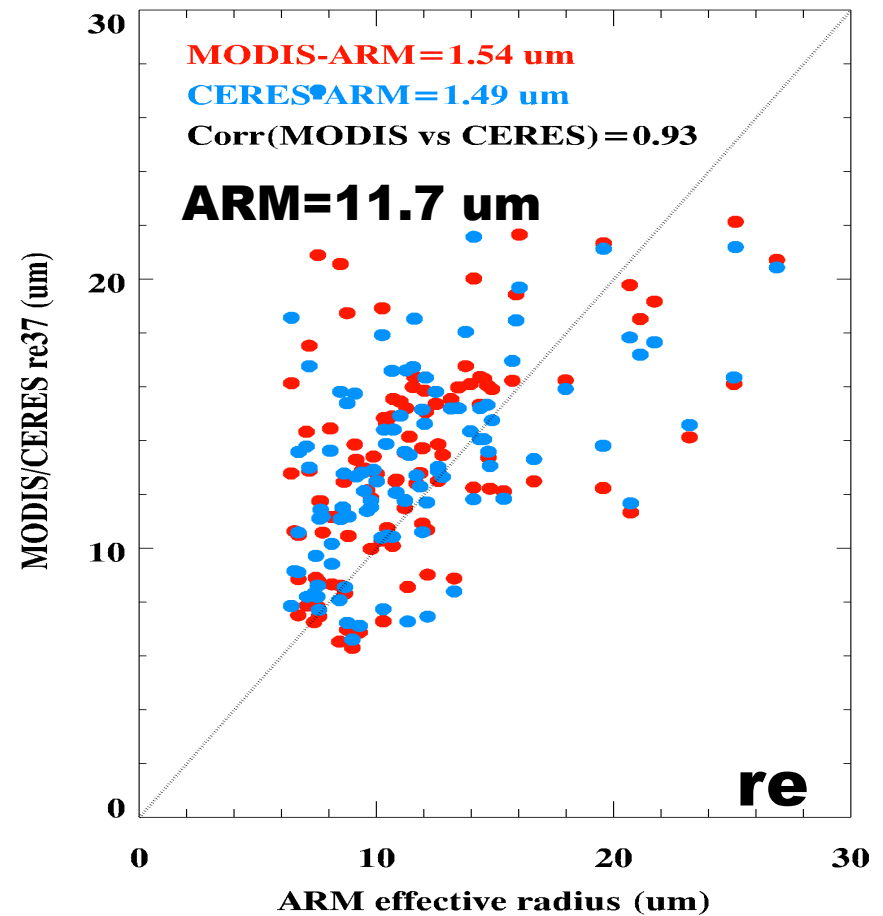
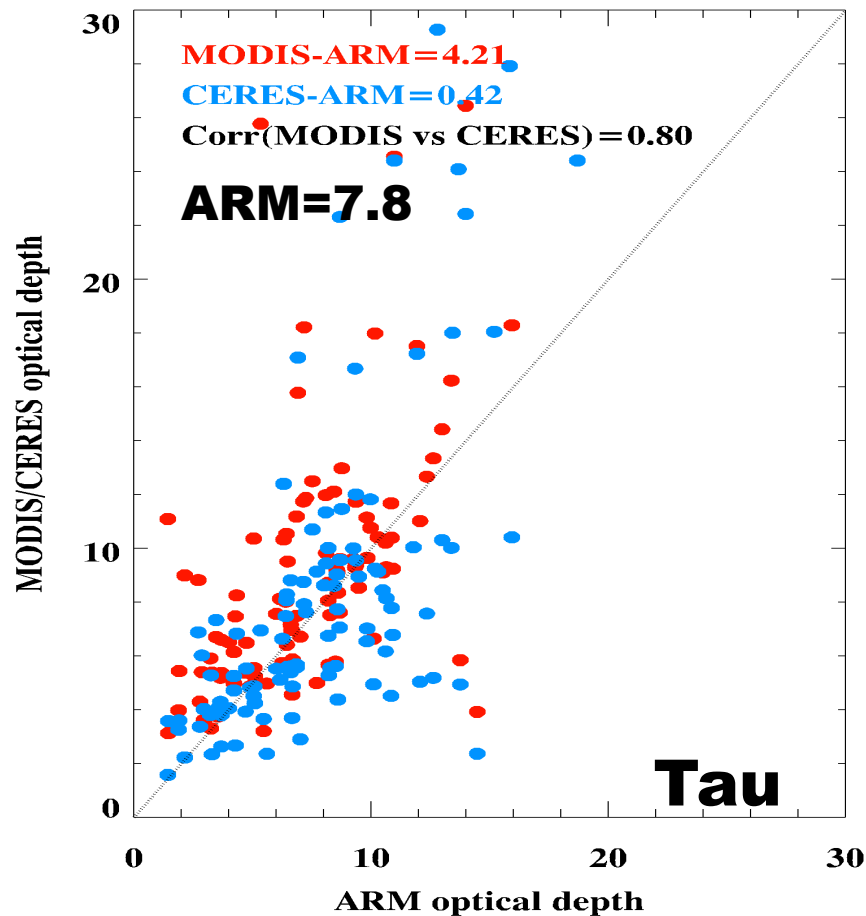
slope of regression



- Terra C5 within 0.1% but Terra C6 is 3.0% > Aqua
- In original C5 calibration, Terra is 3% > Aqua, but CERES team forced Terra = Aqua, but MODIS team did not.

Tau and r_e comparison between ARM and CERES/MODIS

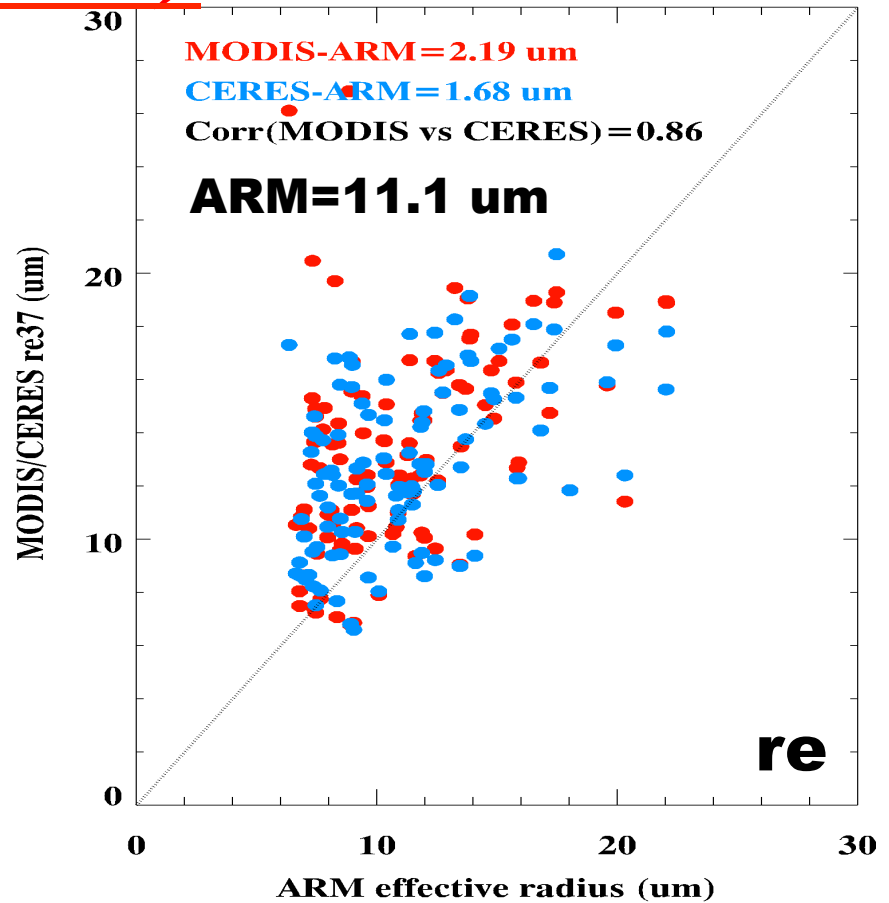
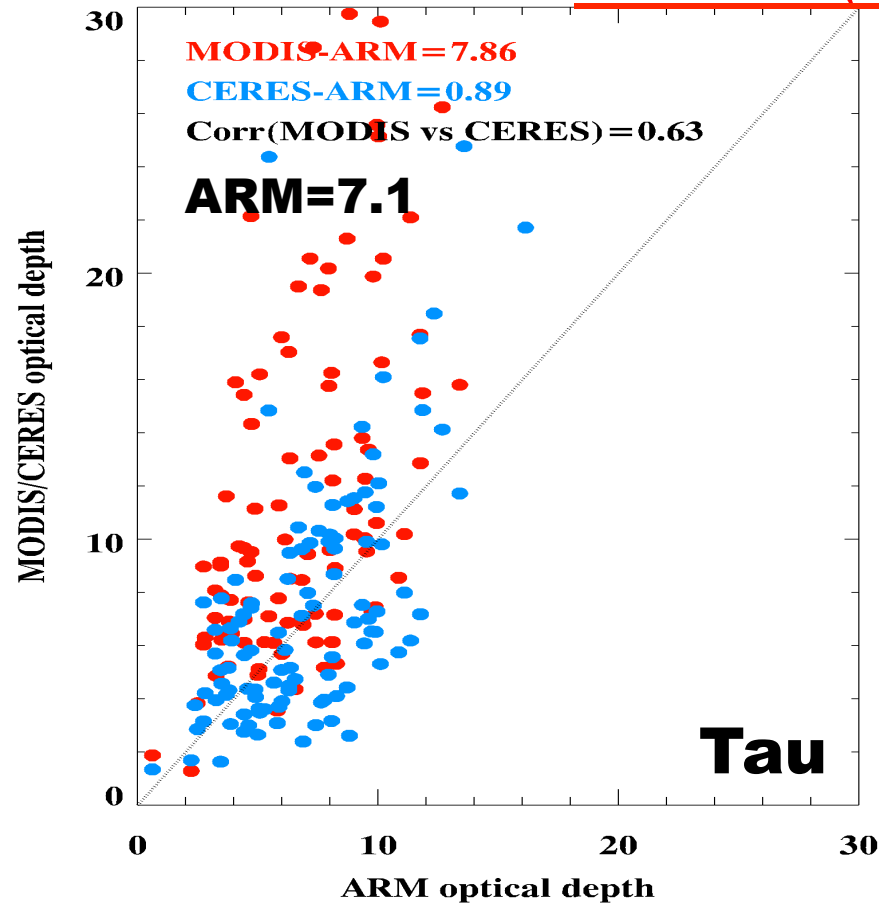
Aqua (snow)



→ The r_e comparison is same as its snow-free counterpart.
→ **MODIS** and **CERES** tau are 4.2 and 0.42 higher than ARM tau, correlation is also lower.

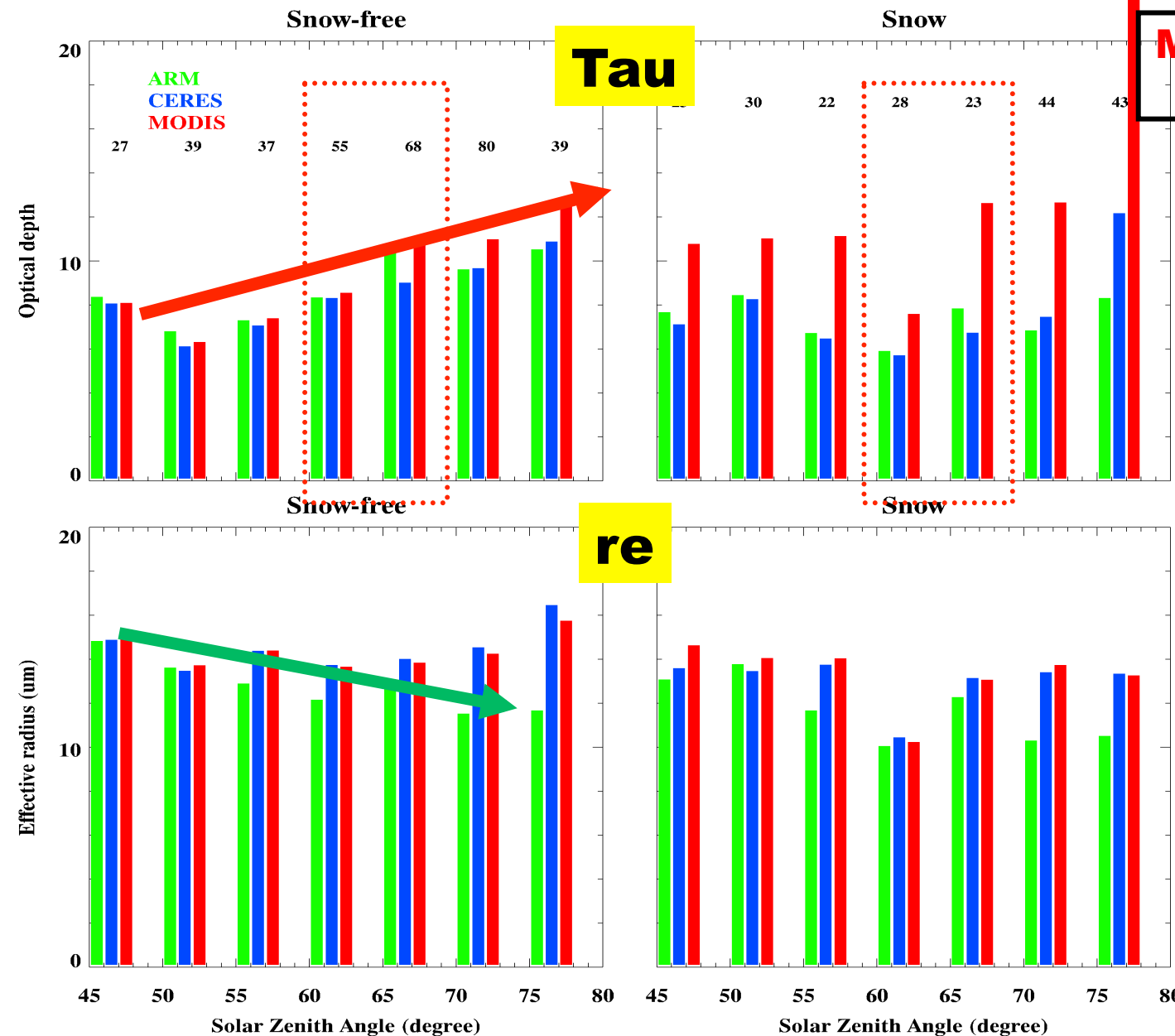
Tau and r_e comparison between ARM and CERES/MODIS

Terra (snow)



- The r_e comparison is similar to its snow-free counterpart.
- MODIS and CERES tau are 7.9 and 0.89 higher than ARM tau, ~doubled the Aqua differences due to Terra C6 3% > Aqua
- In general, Aqua retrievals agree with ARM results better than Terra
- But why MODIS tau >> CERES tau?

Dependence on Solar Zenith Angle (SZA)



**MODIS >> CERES
and ARM?**

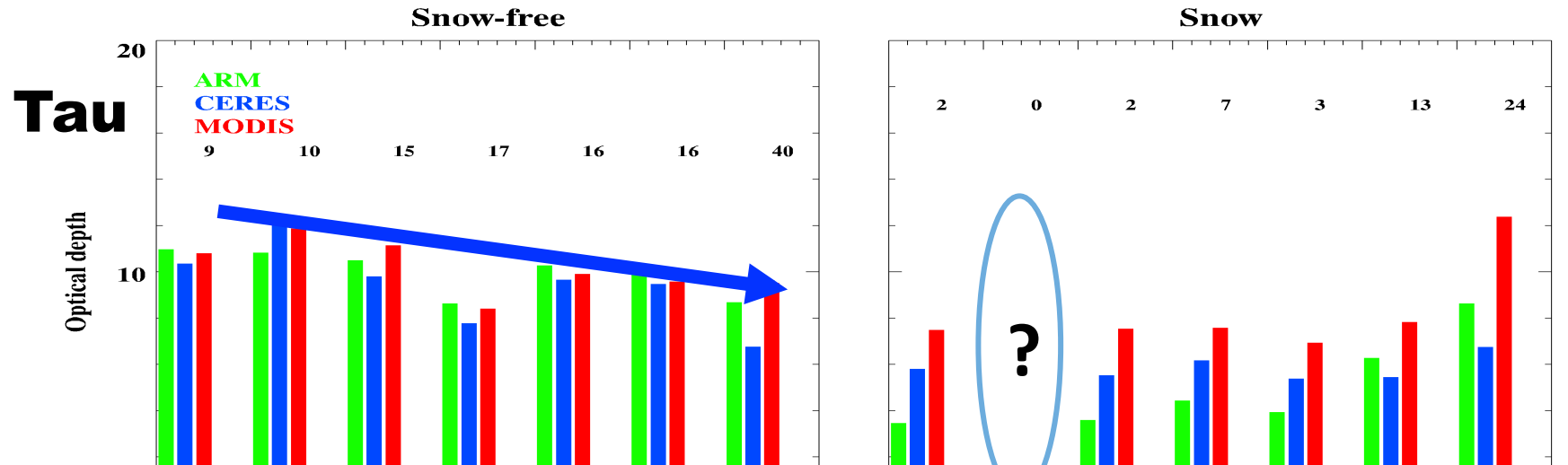
Snow-free (left):

All tau slightly increase with SZA; ARM re slightly decreases but CERES and MODIS do not change or slightly increase at large SZA.

Snow (right):

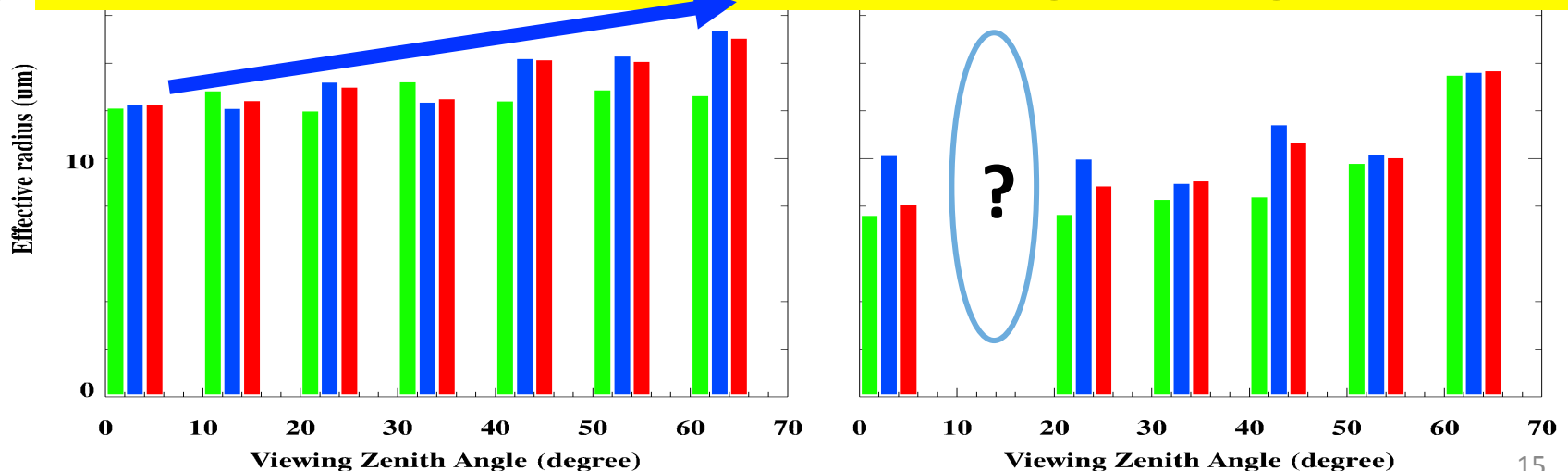
ARM and CERES tau have no obvious trend, but MODIS tau much larger at SZA > 75.

Dependence on VZA when $60 \leq SZA < 70$

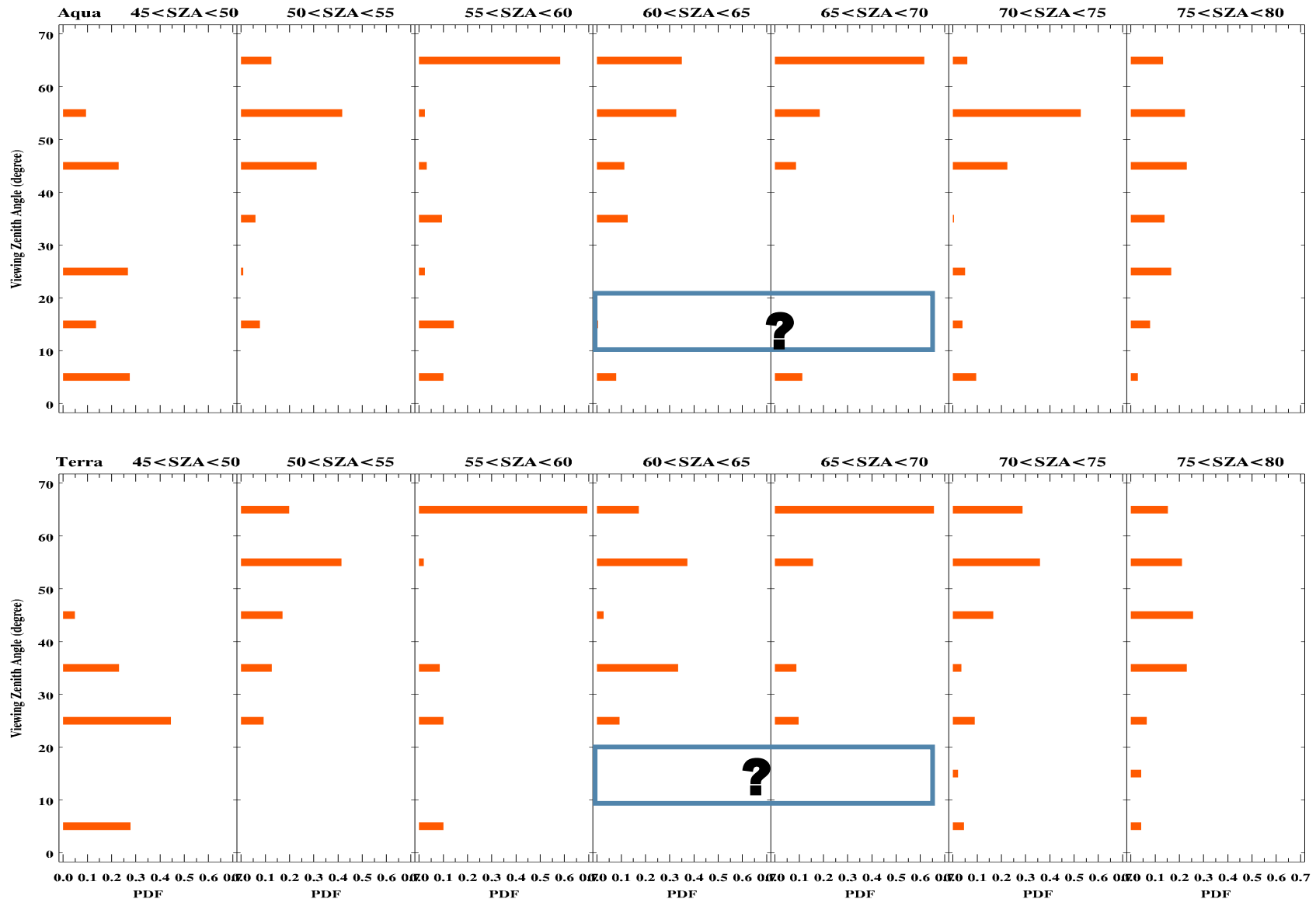


CERES and MODIS tau slightly decrease but re increase with VZA, while ARM do not change too much.

re For snow, all tau and re retrievals are larger at large VZA.

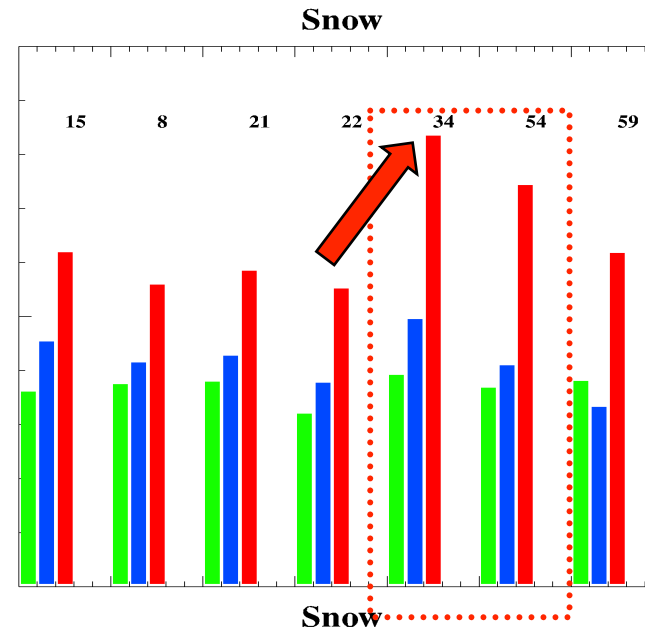
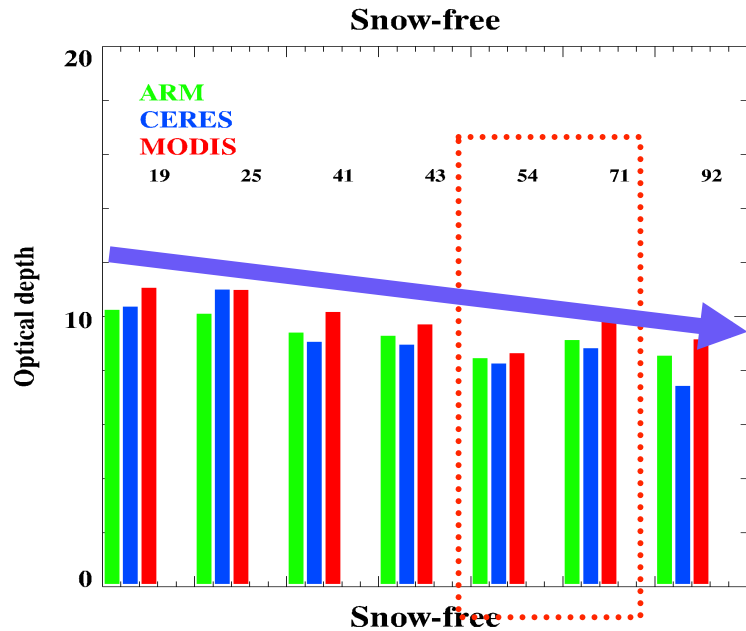


Answer no data at $60 \leq \text{SZA} < 70$ using MODIS 1x1 km²

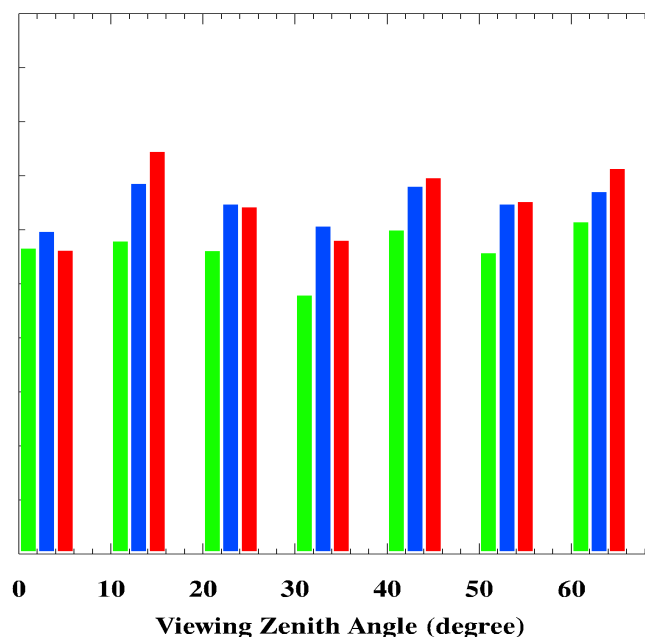
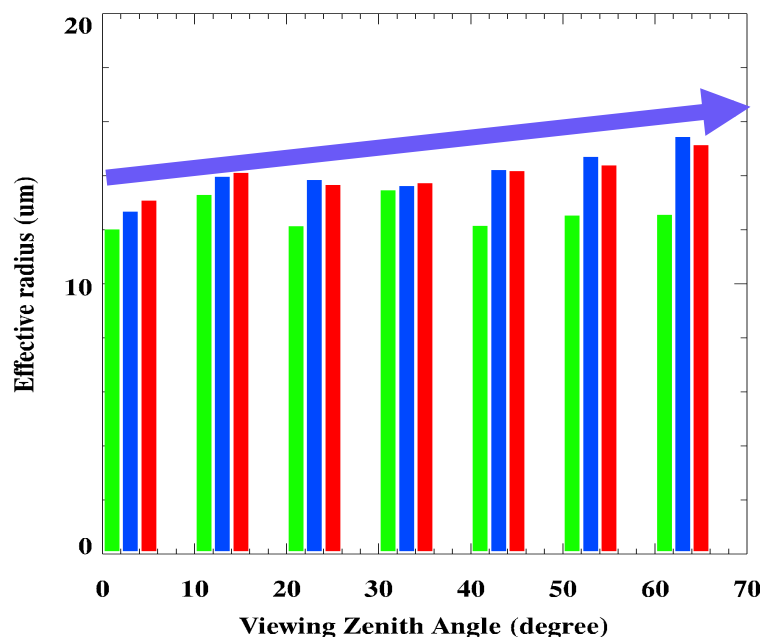


Due to limited samples, some bins without data.
There are no MODIS pixel level data for $10 < \text{VZA} < 20$ at $\text{SZA} = 60-70$.

Dependence on VZA from all samples

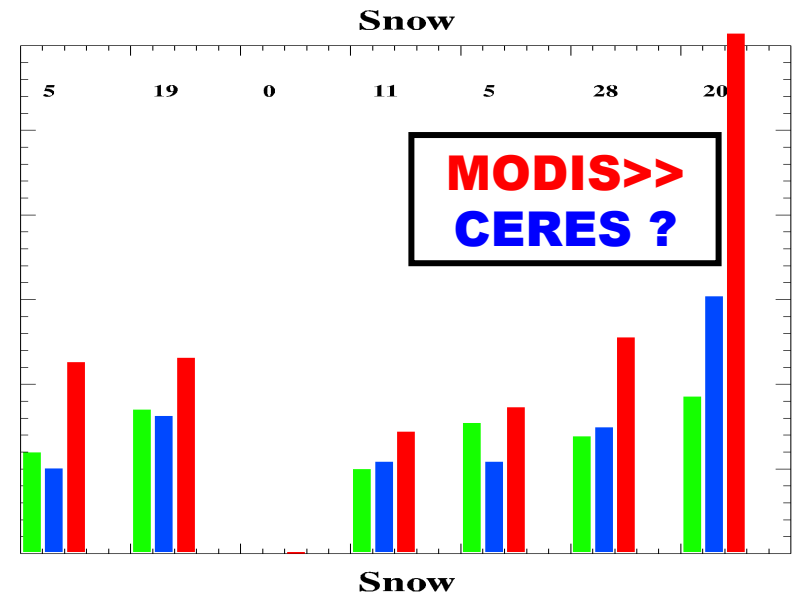
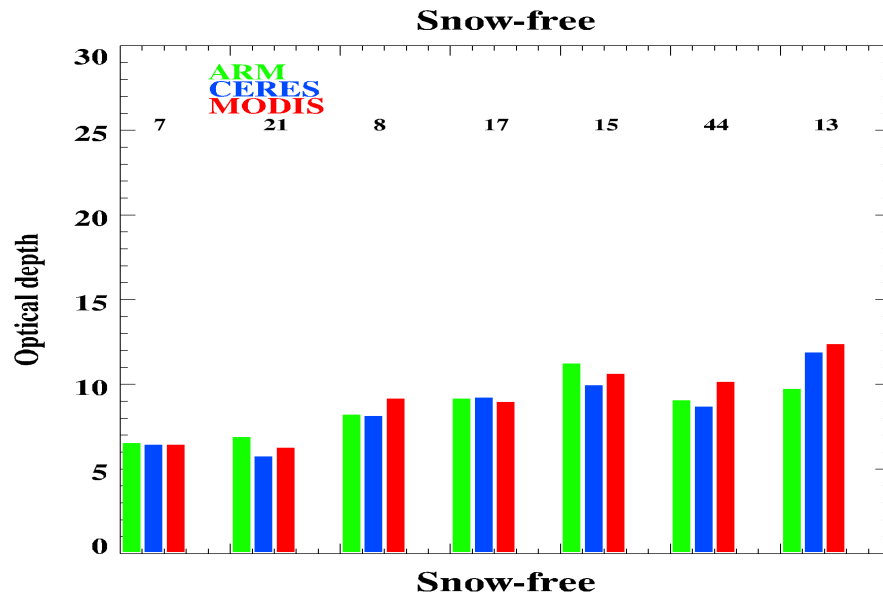


❖ **Snow-free:**
CERES and **MODIS** tau slightly decrease but re increase with VZA, while **ARM** retrievals do not change too much.

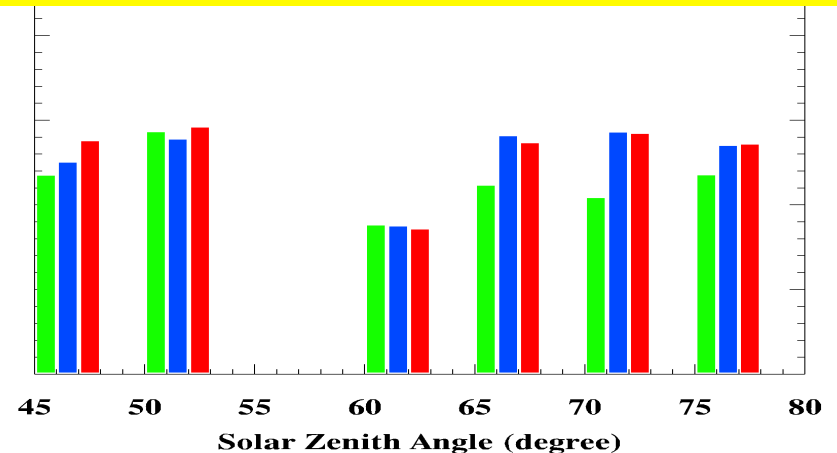
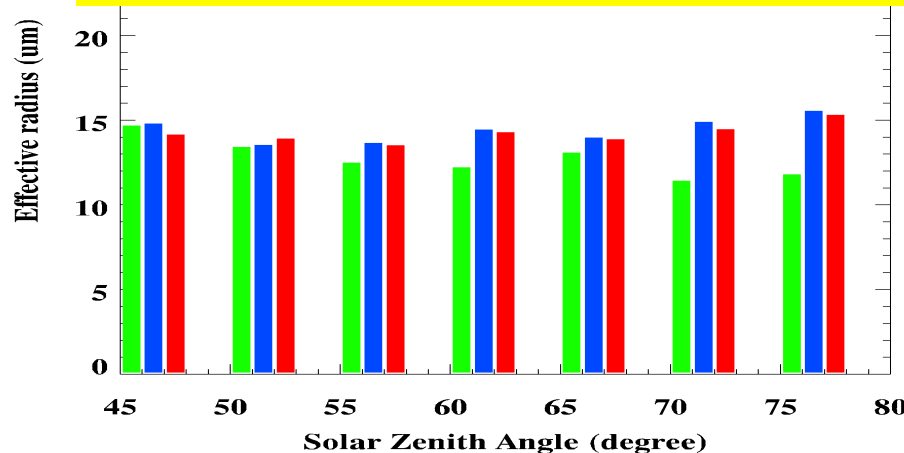


❖ **Snow cases**
 No obvious dependence of **ARM** and **CERES** retrievals on VZA
MODIS tau greatly increase from VZA=30 to 40. We are going to investigate this using 1x1 km² pixel data.

Dependence on SZA when $40 \leq VZA < 60$



**Same conclusion as slide 14, SZA dependence.
We will explore more why MODIS >> CERES at SZA > 75 for snow.**



VZA



- **Why MODIS tau >> CERES Tau for SZA > 75 under snow condition?**
- **There are Tau=150 values in MODIS retrievals.**

Summary

➤ Mean differences between MODIS and CERES retrievals:

	$\tau_{\text{MODIS}} / \tau_{\text{CERES}}$	Corr	$re_{\text{MODIS}} / re_{\text{CERES}}$	Corr
Aqua (snow-free)	9.7 vs 9.1	0.93	14.0 vs 14.0	0.95
Terra (snow-free)	9.6 vs 8.4	0.70	14.3 vs 14.5	0.89
Aqua (snow)	12.0 vs 8.2	0.80	13.3 vs 13.2	0.93
Terra (snow)	14.9 vs 7.9	0.63	13.3 vs 12.8	0.86

In general, both re are same, but CERES tau agree with ARM better than MODIS, Aqua retrievals agree with ARM results better than Terra

➤ SZA dependence:

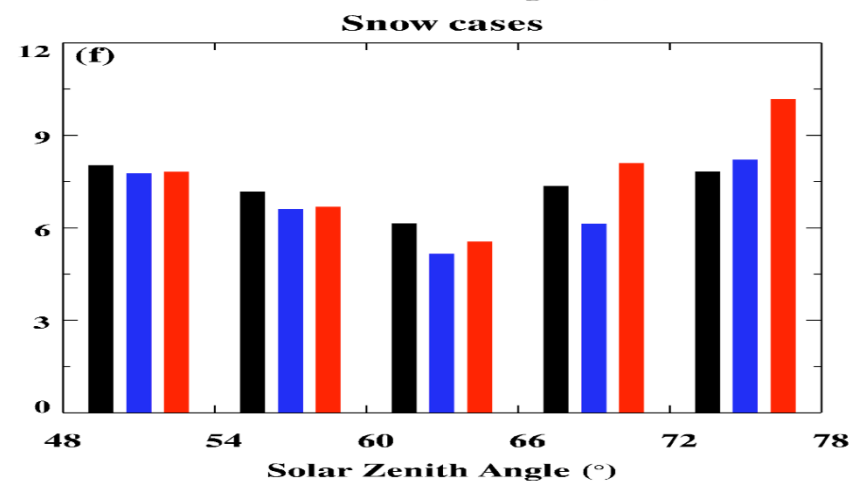
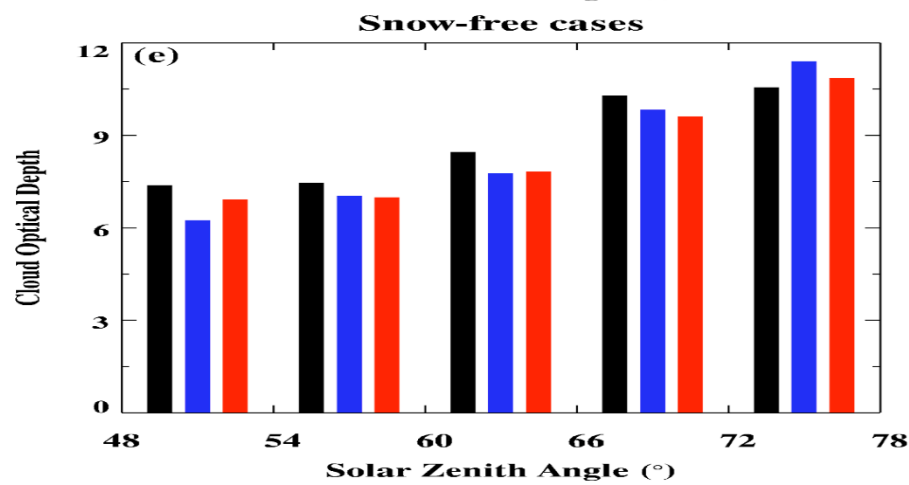
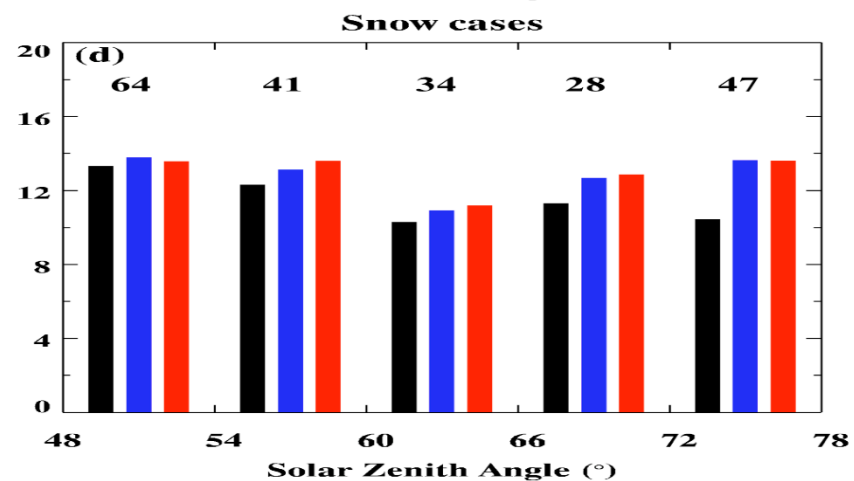
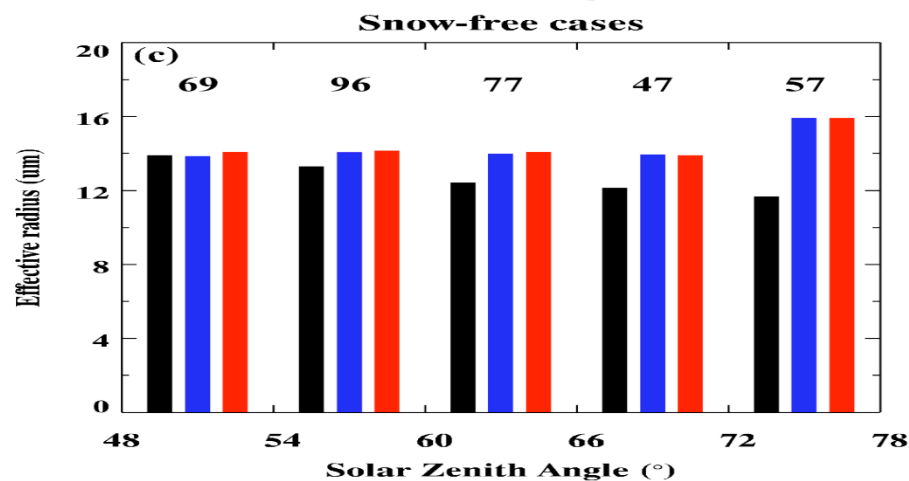
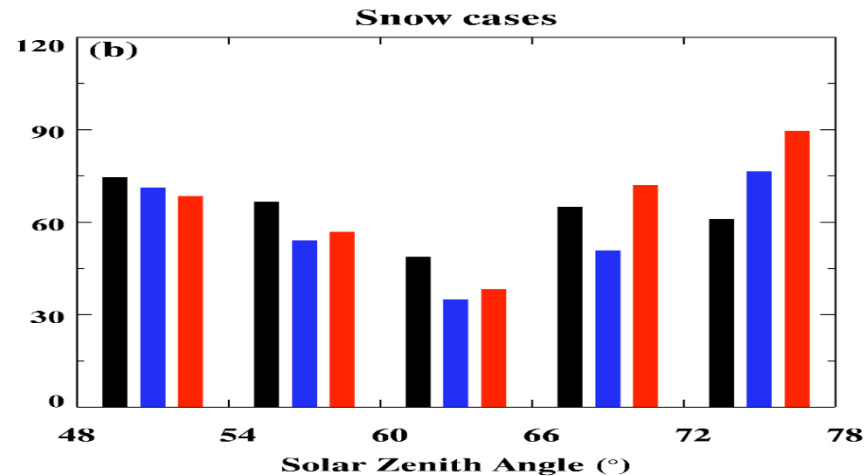
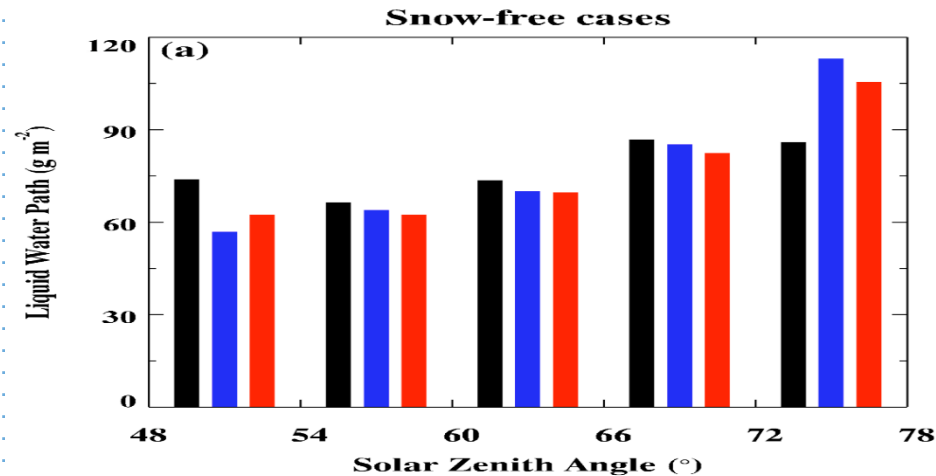
Snow-free: All tau slightly increase with SZA; ARM re slightly decreases but CERES and MODIS do not change or slightly increase at large SZA.

Snow: ARM and CERES tau have no obvious trend, but MODIS tau much larger at SZA>75.

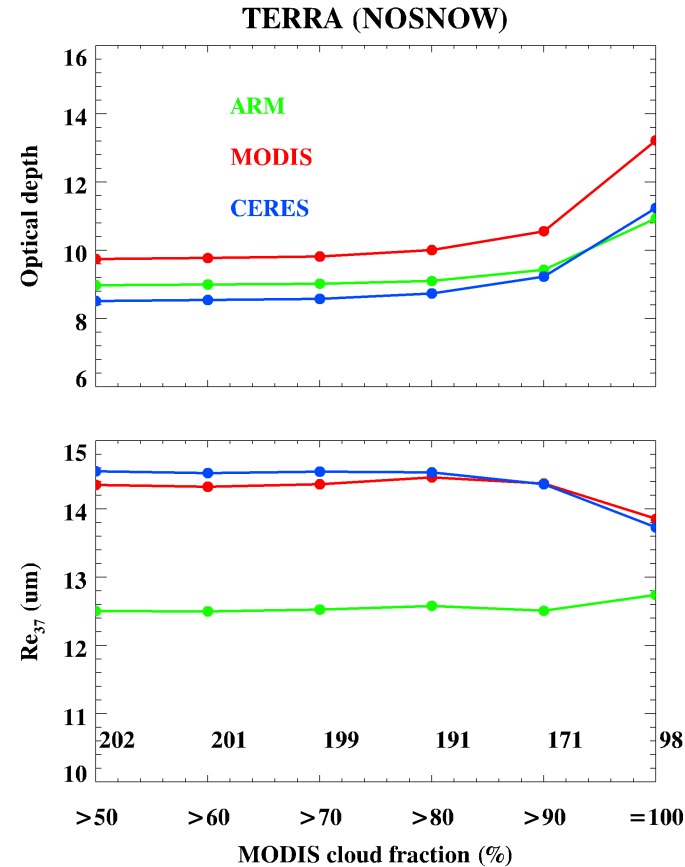
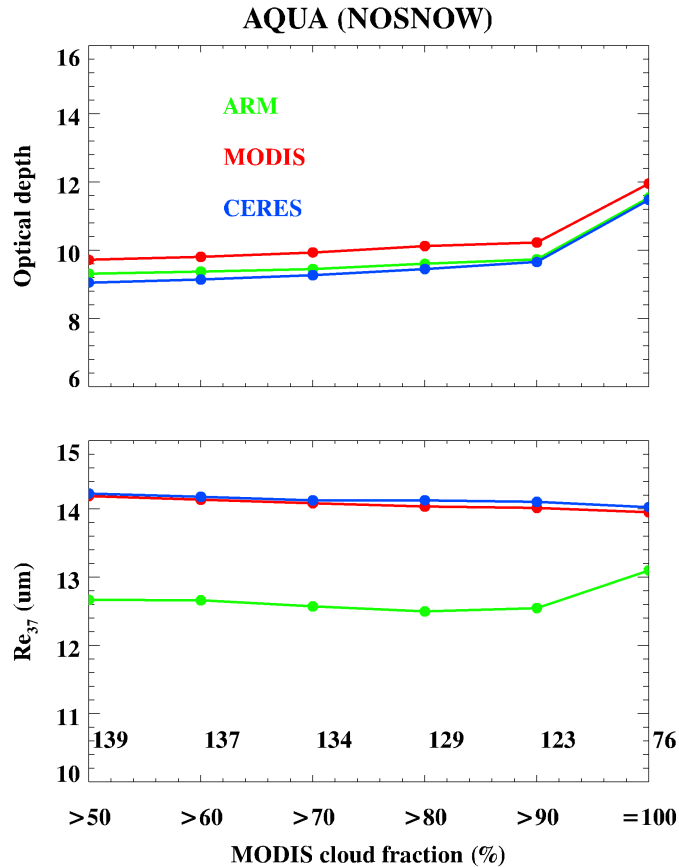
➤ VZA dependence:

Snow-free: CERES and MODIS tau slightly decrease but re increase with VZA, while ARM retrievals do not change too much.

Snow: No obvious dependence of ARM and CERES retrievals on VZA But MODIS tau significantly increase from VZA=30 to 40.

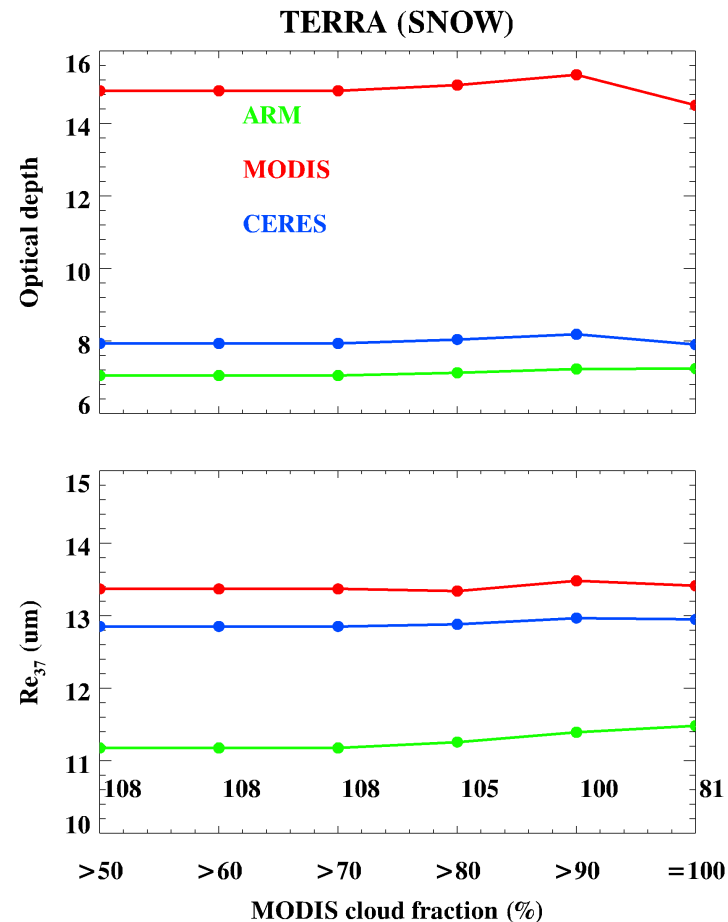
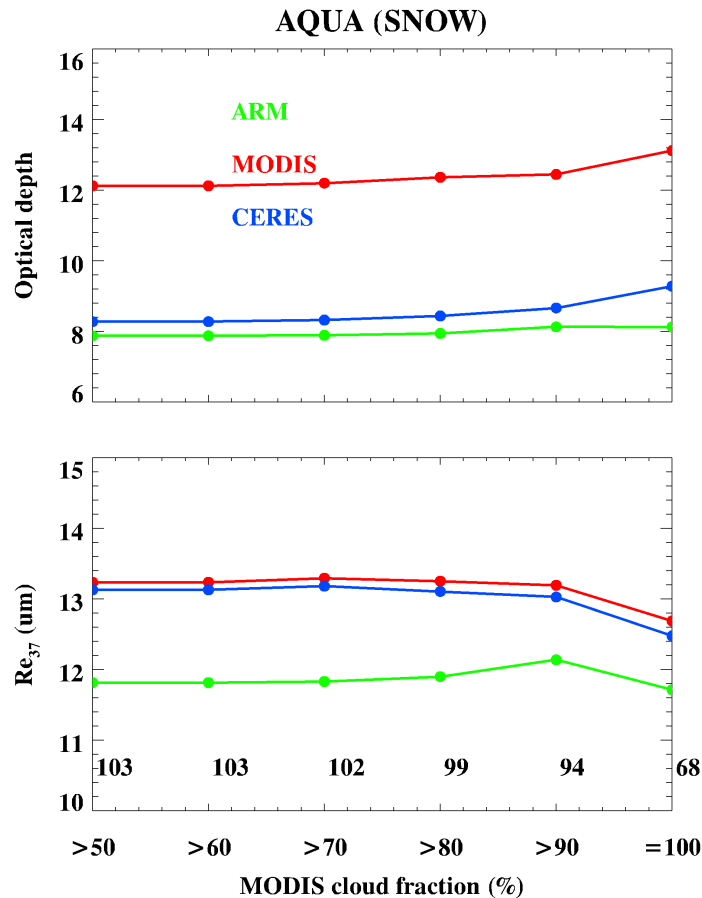


When MODIS cloud fraction $\neq 100$



- Under snow-free condition, the MODIS retrieved τ have the similar trend but slightly greater than these retrieved by CERES and ARM at AQUA overpass;
- CERES retrieved optical depths are closer to ARM retrievals; Both MODIS and CERES retrieved r_e ($3.7\mu m$) are much greater than these from ARM
- The r_e ($3.7\mu m$) at both Terra and Aqua overpasses have much less variation compared to τ .
- Including lower cloud fraction cases is not significantly changed the mean except significantly reducing the sample number at cloud fraction =100%.

When MODIS cloud fraction $\neq 100$



- Under snow condition, the MODIS retrieved τ are significantly different from both CERES and ARM retrievals and the difference is larger at Terra overpasses than that at Aqua overpasses;
- the MODIS retrieved r_e ($3.7\mu m$) are similar to CERES retrievals at Aqua overpasses, but are offset by ~ 0.5 at Terra overpasses;
- The r_e ($3.7\mu m$) at both Terra and Aqua overpasses have much less variation compared to τ .
- Again, including cloud fraction is not 100% has no significantly effect on means.

ARM Northern Slope of Alaska (NSA Site)



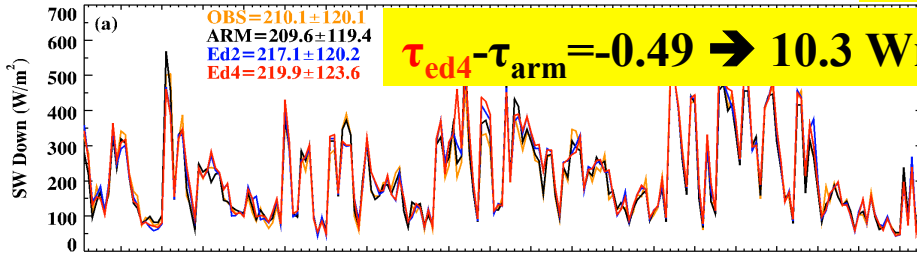
- 1) **Time period: 7 years from March 2000 to December 2006**
- 2) **A total of 206 snow-free cases ($R_{sFC} < 0.3$) and 108 snow cases ($R_{sFC} > 0.3$) have been selected (mixed phase stratus clouds).**
- 3) **ARM cloud microphysical properties are retrieved from the method of Dong and Mace (2003), and CERES-MODIS results are from Minnis et al. (2011).**
- 4) **CERES Ed4 and MODIS cloud results are averaged over a 30 km x 30 km grid box centered on the ARM NSA site. ARM results are averaged over 1-h interval centered at satellite overpass.**
- 5) **MODIS 1x1 km² pixel-level retrievals are used to study the dependence of satellite cloud retrievals on SZA and VZA.**

How sensitive of $SW\downarrow_{SFC}$ and $SW\uparrow_{TOA}$ to optical depth? (snow-free)

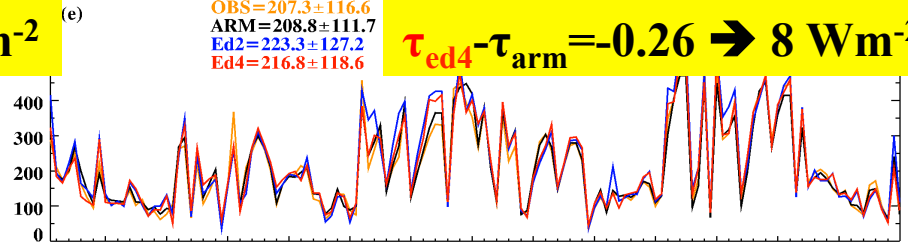
$SW\downarrow_{SFC}$

TERRA snow-free cases

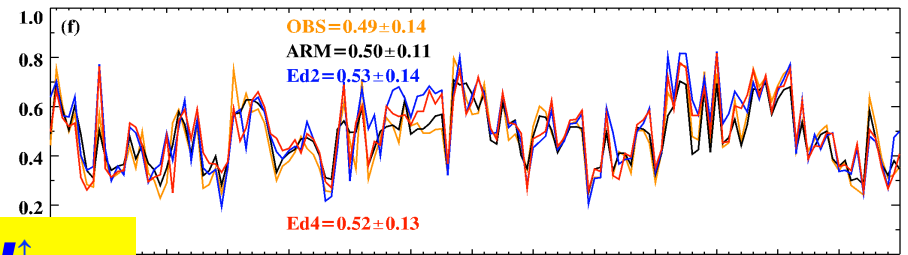
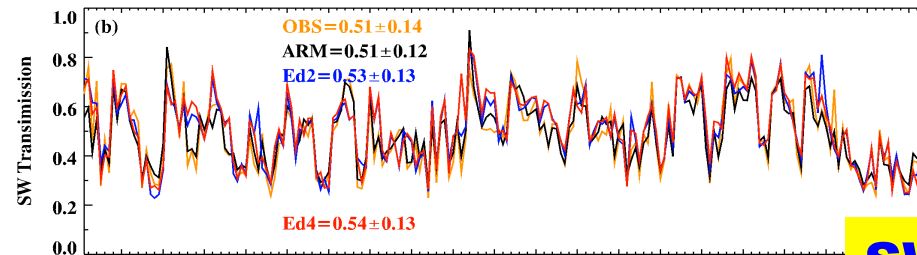
AQUA snow-free cases



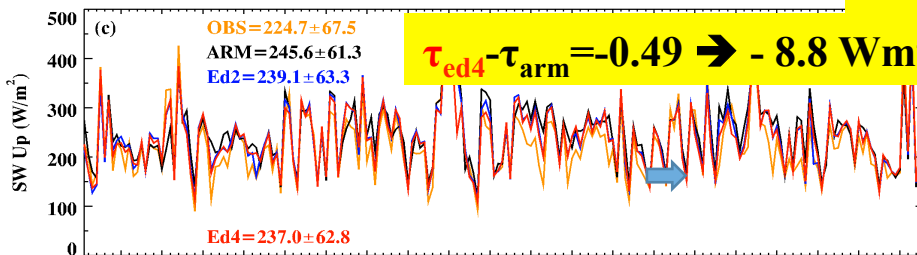
$$\tau_{ed4} - \tau_{arm} = -0.49 \rightarrow 10.3 \text{ Wm}^{-2}$$



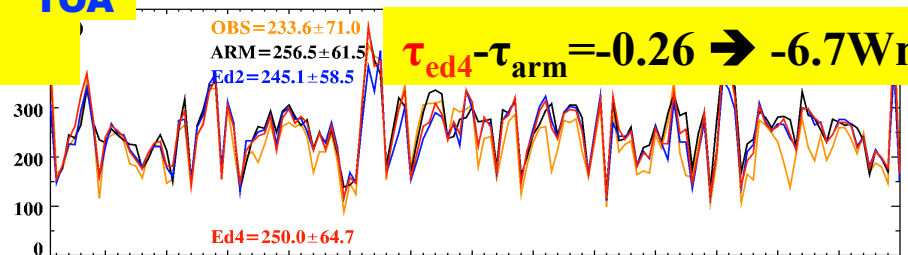
$$\tau_{ed4} - \tau_{arm} = -0.26 \rightarrow 8 \text{ Wm}^{-2}$$



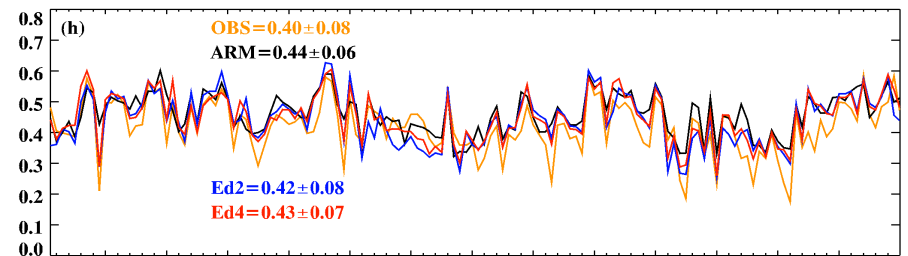
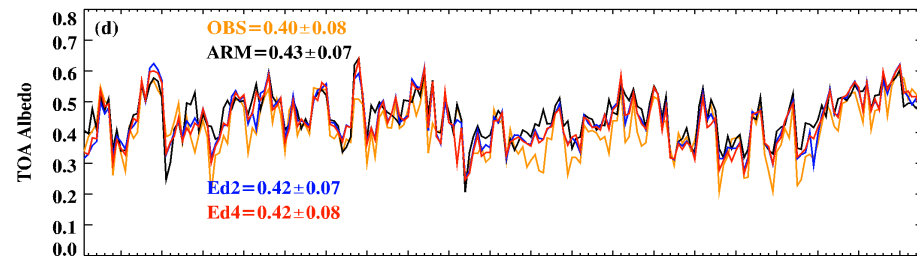
$SW\uparrow_{TOA}$



$$\tau_{ed4} - \tau_{arm} = -0.49 \rightarrow -8.8 \text{ Wm}^{-2}$$



$$\tau_{ed4} - \tau_{arm} = -0.26 \rightarrow -6.7 \text{ Wm}^{-2}$$



Case number

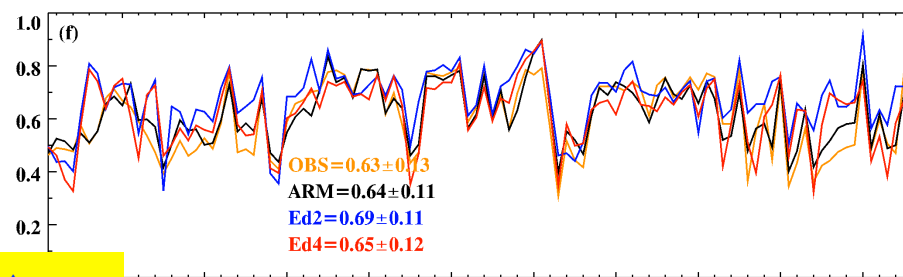
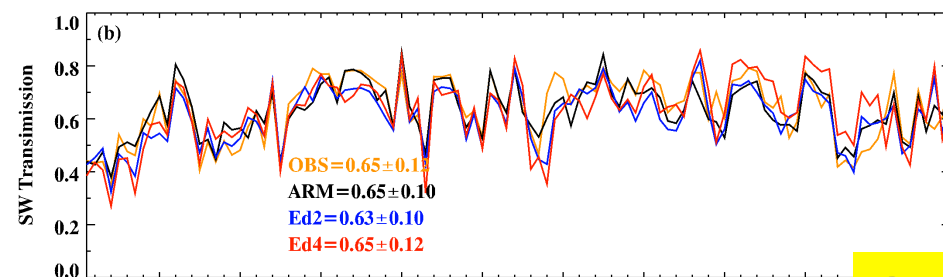
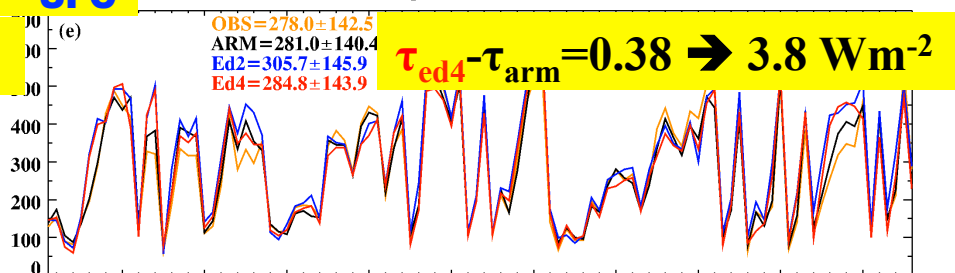
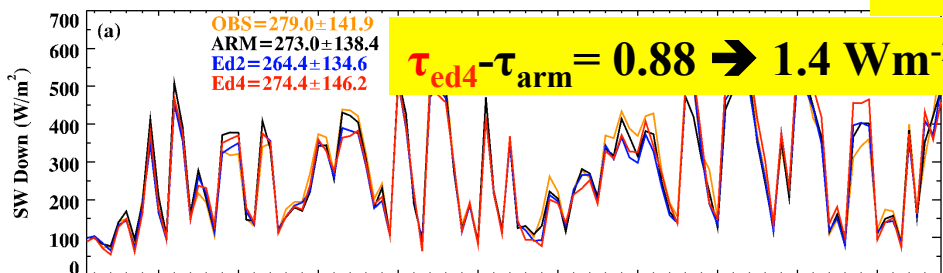
Case number

For snow cases

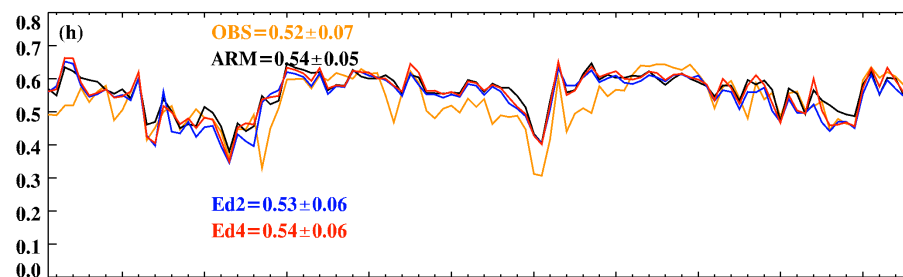
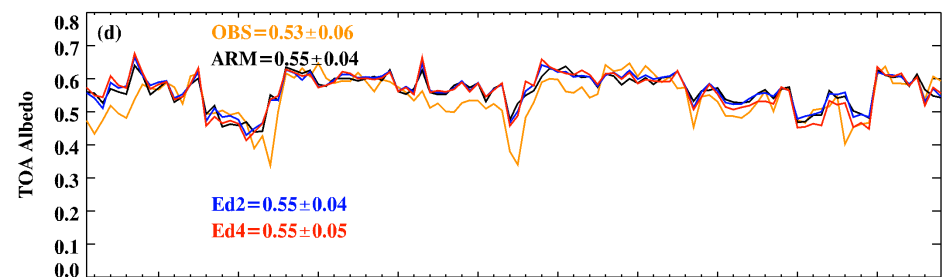
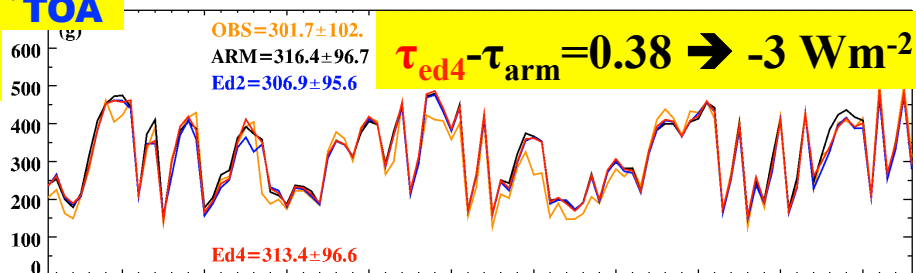
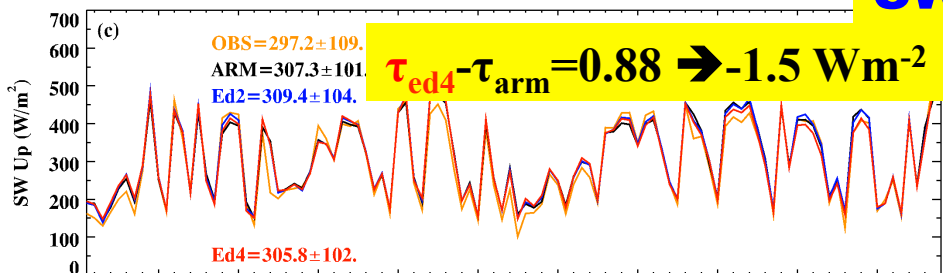
TERRA snow cases

SW↓_{SFC}

AQUA snow cases



SW↑_{TOA}

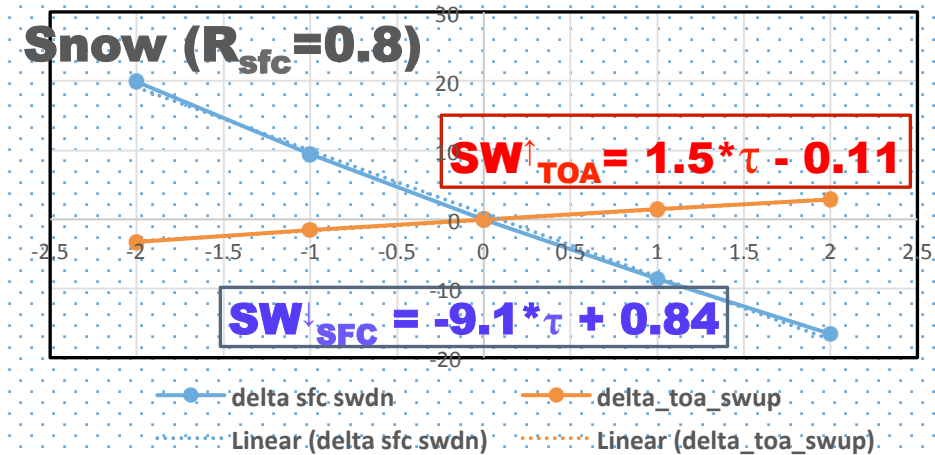
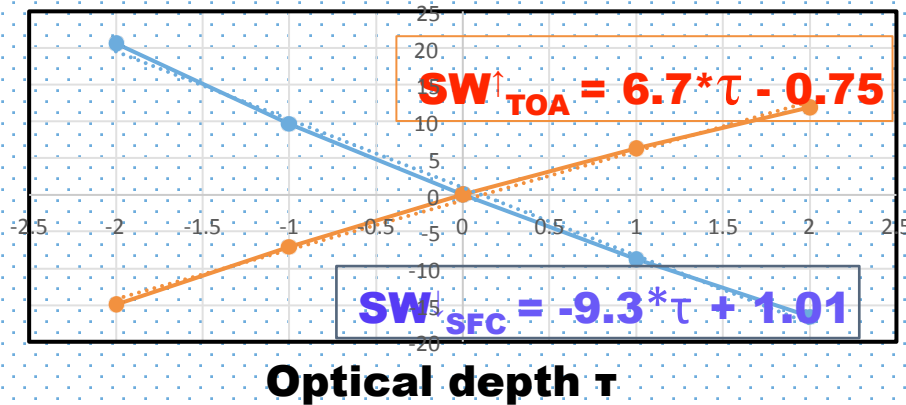


Case number

Case number

Sensitivity test for SW_{SFC}^{\downarrow} and SW_{TOA}^{\uparrow} with $\Delta\tau = \pm 1$ in RTM

Snow-free



$\Delta SW_{SFC}^{\downarrow}$ is same as snow-free, but $\Delta SW_{TOA}^{\uparrow}$ does not change too much when R_{sfc} is high.

Snow-free	$\Delta SW_{TOA}^{\uparrow}$	$\Delta SW_{SFC}^{\downarrow}$
$\Delta\tau = -1$ in RTM	-6.7	9.3
TERRA $\tau_{ed4} - \tau_{arm} = -0.49$	-8.8	10.3
AQUA $\tau_{ed4} - \tau_{arm} = -0.26$	-6.7	8.0

The τ difference between **Ed4** and ARM can attribute to 38% and 26% of SW_{TOA}^{\uparrow} for Terra and Aqua overpasses. They are 45% and 29% of SW_{SFC}^{\downarrow} .

Snow	$\Delta SW_{TOA}^{\uparrow}$	$\Delta SW_{SF}^{\downarrow}$
RTM $\Delta\tau = +1$	1.5	-9.1
TERRA $\tau_{ed4} - \tau_{arm} = 0.88$	-1.5	1.4
AQUA $\tau_{ed4} - \tau_{arm} = 0.38$	-3.0	3.8